Quality Improvement of Indoor Air by Using Heat Recovery Wheel

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Abstract: An energy recovery device transfers sensible and latent heat between the exhaust and supply air streams of a building. There are several different types of energy recovery devices utilize for this project. A rotary air-to-air energy exchanger that can transfer both sensible and latent heat.

Two Air Conditioning systems will be studied - one without an energy wheel (termed as the base case) and one with an energy wheel. The air conditioning system is based on the vapour compression refrigeration system.

There are various heat recovery devices which gives the different methods of heat recovery.

There are two main purpose of this research project. The first is to determine the relaxed relative humidity levels temperature in a building and class room can be possible using an energy wheel. The second is to determine whether any energy and cost savings can be realized with the use of an energy wheel.

Keyword: Indoor Air Quality, Energy Recovery, Wheel Selection, Cost Analysis.

INDOOR AIR QUALITY (IAQ)

Indoor Air Quality defines as the nature of conditioned air that circulates throughout the space where we work and live i.e. the air we breathe during most of our lives. IAQ refers not only to comfort, which is affected by temperature, humidity but also to harmful biological contaminants and chemicals present in the conditioned space. [1]

In a conditioned space, free passage of air is limited, with little or insufficient fresh air ventilation and it produces an indoor air environment with relatively high levels of contaminants, bacteria, fungi and dust. The indoor air will have all of the pollutants of the outdoor or surrounding air and that are generated within the building by people and their activities like smoking, hair sprays, cleaning products, paints and pesticides spray residues, carpeting, copy machines and air-conditioning coolants. As a result, indoor air may contain concentration of some components which are greater than the outdoors ambient air. The composite effect of multiple pollutants can seriously impact human respiratory systems leading to various short term and long term illness.

RELATIVE HUMIDITY

Maintaining indoor air conditions by moderating humidity levels in buildings. There are several methods for moderating humidity levels in buildings. The two main methods are using outdoor ventilation and mechanical cooling equipment. Outdoor ventilation is simply bringing fresh air from outdoors into the space. The problem with this method is that if the indoor air is too humid (above the upper humidity limits), and the outdoor air is also very humid there will be little or no moisture removal. For this reason, this method only works well in cold, dry climates. The other common method uses mechanical cooling equipment to cool and dehumidify the supply air being delivered to the space. The supply air will be able to remove moisture from the space. This solves the problem of only being able to use outdoor air in cold, dry climates. This method however, has very large operational costs, including initial costs of purchasing and installing equipment and energy costs to run the equipment. Since neither of these methods is optimal, recent research has suggested another method: using hygroscopic [2] materials in the space to moderate humidity levels.

A hygroscopic material is one that can readily absorb moisture. Wood is an example of a natural hygroscopic material. In a building, the hygroscopic material can be present in the walls and ceiling of a room, or in the furniture. If the air in a space is humid, the hygroscopic materials will absorb and store some of the moisture, reducing the humidity level in the space. If that space later on becomes too dry, the hygroscopic material will release the moisture back into the space increasing the humidity level of the space. In this manner, hygroscopic materials help to control the humidity level within a space. [2]

ENERGY RECOVERY

Saving energy is not only important for the environment, it also reduces the cost of running buildings, by reducing the amount of electricity or other energy sources that the building consumes. One way of realizing these energy savings is by using air-to-air energy recovery devices. An energy recovery device transfers sensible and/or latent heat between the exhaust and supply air streams of a building. Although there are several different types of energy recovery devices this project utilizes a rotary air-to-air energy exchanger that can transfer both sensible and latent heat.

As shown in Figure 1, the air being supplied to the space passes through the top section of the wheel, from left to right, while the air is being exhausted from the building passes through the bottom section of the wheel, passing from right to left. Inside the energy wheel, the air comes in contact with a surface which is coated with a desiccant material, that is, a material that absorbs water.

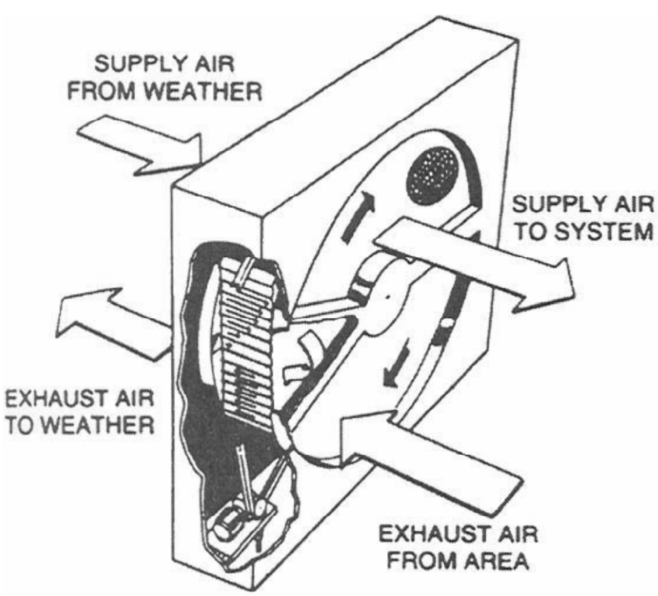


Figure 1: An Air-to-air Energy Wheel.
(ASHRAE Handbook Systems and equipment)

Surface of most energy wheels is made of an aluminum matrix, with corrugated flow channels. The aluminium is in thin sheets (~0.07 mm thick) and is grooved to make small sinusoidal flutes. The majority of the sensible heat transfer is accomplished through this aluminium matrix. The matrix can also be made of non-metallic materials such as paper, plastic or synthetic fibres, but these are more commonly used when little sensible heat transfer is required.

Commonly used desiccant materials are silica gel and 3-4 Å molecular sieve. Each desiccant has its own advantages and disadvantages. Silica gel can absorb high amounts of water and can stand up to acidic environments. It has good adsorption characteristics over a wide range of relative humidity but increasing temperature causes the adsorption capacity to decrease. [3]

The heat recovery wheel or enthalpy wheel is a cylinder, usually 100 to 250 mm deep, packed with a heat transfer medium that has numerous small air passages, or flutes, parallel to the direction of airflow. The flutes are triangular or semi-circular in cross-section.

In a typical installation, the wheel is positioned in a duct system such that it is divided into two half moon sections. The air from the conditioned space is exhausted through one half while outdoor air is drawn through the other half in a counter flow pattern. At the same time, the wheel is rotated slowly (2 to 20 RPM). Sensible heat is transferred as the metallic substrate picks up and stores heat from the hot air stream and gives it up to the cold one. Latent heat is transferred as the medium condenses moisture from the air stream that has the higher humidity ratio through adsorption by the desiccant (with a simultaneous release of heat) and releases the moisture through evaporation (and heat pick up) into the air stream that has the lower humidity ratio.

For sensible heat transfer the medium picks up heat from the incoming hot air stream and stores it. The wheel then rotates so that this section comes in contact with the cold air stream. The heat is released into the cold air stream, causing it to warm up. For latent heat transfer, the medium absorbs moisture from the more humid air stream. The wheel rotates to the other stream and the moisture is released through desorption into the less humid air stream. For total heat recovery both processes take place simultaneously. [4]

BUILDING SURVEY

The Institute Building

The floor plan chosen for the class is based on the floor plan of the mechanical engineering department, KNIT Sultanpur. Sultanpur district is situated 150 km east of Lucknow on the state highway SH34. The Sultanpur district lies at latitude 26°-15' N and longitude 82°-0' E, in the Eastern part of Uttar Pradesh State.

Outside Design Conditions of Sultanpur:

Summer
41 °C DBT
24 °C WBT
Monsoon
34 °C DBT
26.7 °C WBT
Inside Design Conditions:
Summer
24 °C ± 1 °C DBT
50-60% RH
Monsoon
24 °C ± 1 °C DBT
50-60% RH

Indoor air conditions have been taken at air velocity of 6 m/min.

Floor Plan of the Class

The class room has a total floor area of 69.34 m² and height is 3.50 m high.

Construction of the Class Room

The exterior walls of the class room are made from the bricks of 24 x 10 x 8 cm and 1.20 cm plaster on both side of the wall. The U value for this wall is 2.02 W/ (m²·K) (R = 0.453 K/W).

The building roof consists of 20 cm of concrete on the inside. The U value for the roof is 0.52 W/ (m²·K) (R = 1.92K/W). The windows are single glazed and have a U value of 3.18 W/ (m²·K) (R = 0.314K/W). The interior walls are made of 30 cm of brick.

Infiltration and Ventilation in the Class

The infiltration rate through the exterior walls of the building is 800 cm³/(s·m²), or 0.4 air changes per hour (ACH). The ventilation rates for the class are from ASHRAE Standard 62 (2001).

Occupancy in the Class

The occupancy levels for the class room are chosen based on a typical class which has 60 students and one teacher. The class is empty on the weekends. During lunchtime (12:30-13:30) all the students leave the class room.

The metabolic rate for the students is 1.2 met while seating and light work. The relative velocity of the air is set at 0.1 m/s. These values are again taken from ASHRAE (2005).[5]

Equipment and Lighting in the Class

The class room contains no equipment load and 16.2 W/m² light load.The All lights are off on the weekends.

COOLING LOAD CALCULATION

The more refined methods available in the HVAC handbook.

1. Total Equivalent Temperature Difference
2. Cooling Load Temperature Difference
3. Transfer Function Method [6]

SENSIBLE HEAT GAIN THROUGH BUILDING STRUCTURE BY CONDUCTION

The heat gain through a building such as wall, floor, roof and windows constitutes the major portion of sensible heat load.

A little consideration will show that the heat passing through a wall is first recieved at the wall surface exposed to the region of higher air temperature by radiation, convection and conduction. It then flows through the material of the wall to the surface exposed at the region of lower air temperature.

Thus, the heat transferred or gained through a wall under steady state condition is

$$Q = h_o (t_o - t_1) A + (k/x) (t_1 - t_2) A + h_i (t_2 - t_i) A$$

$$Q = U A (t_o - t_i) \quad [6]$$

SOLAR HEAT GAIN THROUGH GLASS AREAS

The heat gain through the glass areas constitutes a major portion of the load on cooling appratus.

Heat gain through glass = transmitted solar radiation + heat flow by convection and radiation heat exchanges between glass and indoor surfaces. [6]

HEAT GAIN DUE TO INFILTRATION

The amount of infilterated air through window and wall is = L × B × H × ACH/ 60 m^3/min

HEAT GAIN DUE TO VENTILATION

The ventilation (supply of outdoor air) is provided to the conditioned space in order to minimise odour, concentration of smoke carbon dioxide and other undesirable gases so that freshness of air could be maintained.

HEAT GAIN FROM OCCUPANTS

The heat gain from occupants is based on the average number of people that are expacted to be present in the conditioned space. The heat load produced by each person depand upon the activity of the person.

HEAT GAIN FROM LIGHTING EQUIPMENT

The heat gained from electric lights depands upon the rating of lights in watts, use factor and allowance factor. Mathematically, the heat gained from electric lights is given by

Q = Total wattage of lights × Allowance factor

			Project Date			Class Room 10-Aug-12				
					Cooling-load Summary					
S. No.	*Area Name*	*Area (m^2)*	*Light Load (W/m^2)*	*Equipment Load (W/m^2)*	*Occup*	*Total Fresh Air (CMM)*	*Summer Dehum CMM*	*Summer TR Total*	*Monsoon Dehum CMM*	*Monsoon TR Total*
1	Class room	70	16.15	0.0	61	17.263	46	7.04	40	7.9
	Total	70				17.263	46	7.04	40	7.9

TECHNICAL SPECIFICATION OF HEAT RECOVERY WHEEL

The Heat Recovery part shall include 'ECOFRESH' and make enthalpy wheels and shall have minimum recovery of 75% of total heat, i.e. both sensible and latent (each being 75%). The recovery of sensible and latent shall be equal. Necessary computerized selection of the wheel should be provided along with the offer to justify the same. The wheel shall be made of pure aluminum foil coated with molecular sieve desiccant with pore diameter of 3 ú. The cross contamination between the two air streams shall be nil and leakage less than 0.04%. The wheels shall have non contact labyrinth seals for effective sealing between the two air streams. [7]

HEAT RECOVERY WHEEL SPECIFICATIONS

Rotor/wheel matrix shall be of -The substrate or wheel matrix should be only of pure aluminum foil so as to allow.

(a) Quick and efficient uptake of thermal energy.
(b) Sufficient mass for optimum heat transfer.
(c) Maximum sensible heat recovery at a relatively low rotational speed of 20 to 25 rpm.

Non metallic substrates made from paper, plastic, synthetic or glass fiber media, will therefore, not be acceptable.

The substrate shall not be made from any material which is combustible or supports combustion like synthetic fibrous media.

The wheel has to be certified as per ISO 846 with 0% fungal and bacterial growth at 95% Relative humidity and above.

Fire Rating

NFPA - 90A certification with 0% for flame spread classification should be confirmed by manufacturer.

Pressure Drop

The pressure drop across the rotary heat exchanger shall not exceed 0.254 cm of water gauge for every 0.5 m/s face velocity, or part thereof, for the minimum stated / required latent recoveries / efficiencies.[7]

IMPROVEMENT OF IAQ WITH HEAT RECOVERY WHEEL

When return air (moist) is cooled at constant pressure to a temperature below its dew point, some of the water vapour condenses. This technique is used for cooling and dehumidification of supply air in a conventional air conditioner. Figure 2 shows moist return air enters at State 1 and flows across the cooling coil through which the refrigerant circulates. Some of the water vapour initially present in the return air condenses. The cooled and dehumidified supply air exits from the cooling coil at State '2'.

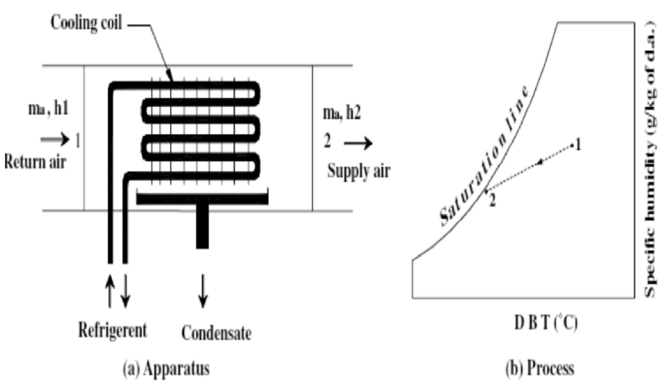


Figure 2: A Conventional Air-conditioning System

The specific cooling capacity of supply air (Figure 2) in conventional AC system is

$$\Delta H_c = (h_1 - h_2)$$

Moisture removal capacity of supply air (Fig. 1) in conventional AC system is

$$M_c = m_a (w_1 - w_2)$$

The cooling capacity of supply air and the COP are [8]

$$Q_c = m_a \times \Delta H_c$$

$$COP_c = Q_c / w_c$$

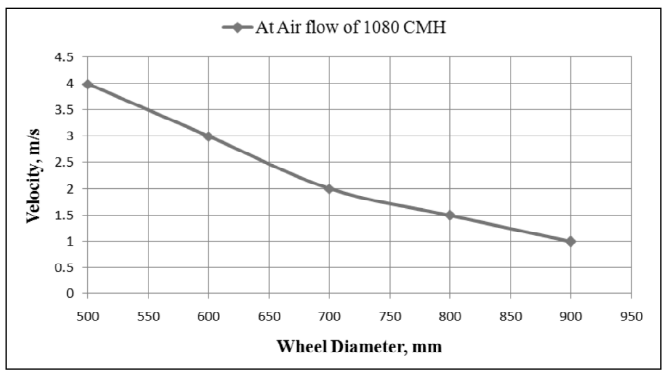
RESULTS AND DISCUSSION

In this paper we are studies one class room of KNIT Sultanpur. In the class room the fresh air flow rate is 1080 CMH.

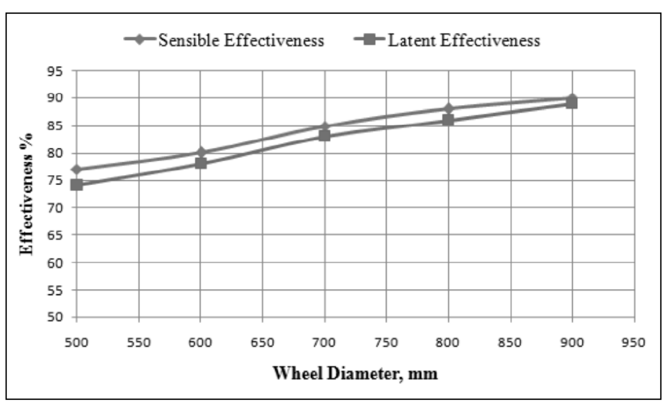
The wheel selection for this case studies is shown below.

The relationship between the wheel diameter and the face velocity of air for constant air flow rate of **1080 CMH** for the class room of KNIT Sultanpur. As the wheel diameter increases the velocity decreases because for the constant air flow rate the contact area increases due to which velocity decreases.

The relation between the wheel diameter and the effectiveness also comprises between the sensible effectiveness and latent effectiveness. When wheel diameter increases both the effectiveness increases because the air flow rate is constant i.e. **1080 CMH** and area of contact increases.



Effect of velocity with variation of Wheel Diameter at constant Air flow of 1080 CMH



Comparison of Sensible Effectiveness and Latent Effectiveness with Wheel Diameter at Air flow rate of 1080 CMH

Wheel Selection for Class room

S. No.	*Project Name*	*Total Fresh Air (CMH)*	*Total TR*
1.	Class Room	1080	7.9

COST ANALYSIS

Annual Energy Savings Calculation for Class Room (Knit Sultanpur)

VLI for Sultanpur 840.28Tonhrs/CMM

This means that the total load for bringing one CMM of fresh air from weather condition to space neutral conditions (22 deg C and 55% RH) is 747.70 Ton-hrs/CMM.

Sensible Load Index –226.86 Ton-hrs/CMM- year

Latent Load Index – 813.42 Ton-hrs/CMM-year

Total Fresh Air 17.263 CMM

Sensible Load on Yearly basis in Ton Hrs

= VLI × CMM

= 226.86 × 17.263

= 3916.28 Ton-hrs

Latent Load on Yearly basis in Ton Hrs

= VLI × CMM

= 813.42 × 17.263

= 14042.06 Ton-Hrs

Total Load on Yearly basis in Ton Hrs

= VLI × CMM

= 840.28 × 17.263

= 14505.75 Ton-Hrs

HVAC Power consumption = 1.1 KW

Rate of Electricity = Rs.6/ KW

No. of operating Hrs/ Day = 8 Hrs.

No. of operating Days/Year = 250 Days (Assume)

Hence energy saving in running cost

$$= \frac{17.263 \text{ x } 840.28 \text{ x } 6 \text{ x } .78 \text{ x } 8 \text{ x } 250}{365 \text{ x } 24}$$

= Rs. 15499.29

TFA fan power consumption

= Rs. 2957

Net Power Saving/ Yr = Rs.15499.29 – 2957

= Rs. 12542.29

Cost of TFA = Rs. 63500 (Inc. all taxes, Insurance and packing)

Cost of Installation including ducting and Insulation

= Rs. 7000 (approx.)

Total cost of the system = Rs. 63500 + 7000

= Rs. 70500

Reduction in Installed TR = 2.27 KW

AC Cost / TR (Installed) = Rs. 30000

Reduction in HVAC Cost =2.27 × 30000

= Rs. 68100

DG Cost (approx.) = Rs. 8000 per TR

Reduction in DG Cost = 2.27× 8000

= Rs. 18160

Reduction in Cost = 68110 + 18160

= Rs. 86270

Payback = Total Cost of the system - Reduction in Cost

= (-ve) 70500 – 86270

= Rs. 15770

Yearly Energy Saving cost = Rs. 12542.29

Saving in Ist Year = Rs. 12542.29 + 15770

=Rs. 28312.29

Saving in 15 Years life = 28312.29 + 14 ×12542.29

= Rs.2,03,905

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